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Form 1/77

Patents Act 1977

❶ Title of invention

1 Please give the title of the invention

DRILLING BIT ASSEMBLY AND APPARATUS

❷ Applicant's details

❑ **First or only applicant**

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2b If you are applying as an individual or one of a partnership please give in full:

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2c **In all cases**, please give the following details:

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ADP number *(if known)*: 05871967001 KAM

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❑ **Second applicant** ***(if any)***

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Agent's name WILSON, MICHAEL JOHN

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4 Agent's or applicant's reference number *(if applicable)* 8371

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5 Are you claiming that this application be treated as having been filed on the date of filing of an earlier application?

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		Continuation sheets for this Patents Form 1/77	–
Claim(s)	4	Description	22
Abstract	–	Drawing(s)	18

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Priority documents *(please state how many)*	
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Patents Form 9/77 – Preliminary Examination/Search	
Patents Form 10/77 – Request for Substantive Examination	

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Date 4th February 1994
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DRILLING BIT ASSEMBLY AND APPARATUS

This invention concerns drill bits for drilling, coring or removing material from a geological subsurface formation.

Such drill bits have cutters which are either rigidly mounted on the bit body or on an extension of that body e.g. blades or studs in the body, or may be mounted on roller cones which can rotate around axles rigidly fixed to the bit body. On the side of the drill bit usually distant from the cutters, such drill bits have a connector, usually threaded, which allows a rigid connection to be made between the bit and the bottom hole assembly and hence the drill string. In use the bit rotates and moves up and down. Eventually the bit is worn out or prematurely broken.

The replacement of a bit involves high cost in lost time as well as the cost of the new physical equipment. The problem of breakage of bits is thus very important in the drilling industry.

In relation to diamond faced bits for cutting or scraping such as diamond faced studs or faces, especially polydiamond crystal (PDC) wafer facing, the cutter comprising the diamond facing may become prematurely broken or dislodged. One reason for the breakage of PDC bits is that caused by vibration of the bit on the end of the very long drill pipe, the vibration resulting e.g. from interaction of the bit and the formation, or of the drill string and the well bore, and causing motion of the bit, which is not concentric nor at uniform speed, e.g. causing slip-stick, bit whirl and bit bounce.

Antiwhirl bits have been described and used in which the cutters are not uniformly distributed around the bit; in at least one place instead of a cutter there is a frictionless pad, the effect of which is that on contact of it and the rock, the bit slides over the rock surface instead of gearing with it. Although antiwhirl bits have in some cases enabled PDC bits to drill into harder formations, they have been less successful in highly interbedded formations, eg. when drilling through rocks of variable or different hardness, which results in vibration of the bit. This problem is especially acute with exploratory wells where the nature of the rocks and the location of their interfaces is not accurately known. Because the cutters are in contact with different rocks, the resultant side force on the bit can no longer be maintained within the low friction pads so the low friction pads of the antiwhirl devices lose their effectiveness. There is thus vibration, an eccentric hole and breakage/dislocation of the cutter.

We have now invented a drill bit assembly which is dynamically more stable and may be used to drill a less eccentric hole for a longer period without breakage or dislocation of the cutter, or breakage to the bit itself.

The present invention provides a drill bit assembly, which comprises a first member and a second member, said first member being for attachment directly or indirectly to a drill string, and said second member carrying at least one means for drilling e.g. a cutter or cone, which assembly also comprises means for holding said members together and for transferring torque and weight from said first member to said second member and drill means, and means allowing tilting of or relative lateral movement of at least one of (a) said first member relative to said second member, and (b) said second member relative to said drill means.

The first member and second member may be of any cross section e.g. square, rectangular, hexagonal or other polygonal, but are preferably rounded such as elliptical but are especially of substantially circular cross section. The members may be of

0.5 - 30 inch e.g. 4-17.5 inch diameter. The first member is the part of the bit which is to be joined to the bottom hole assembly, and hence to the drill string; the join to the bottom hole assembly may be direct or via a motor. The join is preferably via threads on the first member and bottom hole assembly, especially male threads on the first member engaging with a threaded recess in the bottom hole assembly. The first and second member are usually of metal such as steel, or brazing alloys, or of tungsten carbide and may be of lighter or heavier guage than the drill pipe, which connects it to the rotation means at the drilling rig. Each of the first and second members may be solid, but is usually hollow or has a passage parallel to or along its longitudinal axis; especially both have a passage which co-operates to allow flow of drilling fluid from the drill pipe through said members towards the drill means, and, especially the second member, may incorporate one or more surface holes or nozzles for ejecting this fluid.

The second member may be of the same steel or other ferrous metal as the first member, or may be of matrix material and may have been moulded directly to the desired shape. The second member carries the drill means. The bit profile may be rectangular e.g. flat, or curved e.g. hemispherical or single- or double- parabolic.

The second member is the part of the bit on which the drill means is mounted. The drill means may be a means for compression fracturing of the material to be drilled and/or scraping, abrading or cutting that material. Among suitable drill means are roller cones and cutters such as PDC wafers; for convenience the drill means will hereafter be exemplified by a cutter, though similar approaches apply with other drill means (unless otherwise stated). The cutters may be arranged uniformly or non uniformly on the surface of that member distant from the side near said first member. The said side of the second member, on which the cutter(s) are mounted, may be convex rather than concave, or may be protrusions of this second member. The said protrusions may be

an integral part of the said second member, in which case they will usually resemble blades, or they may be rotatable roller cones. The said protrusions may be disposed radially and straight, or radial and curved in plan view or in other dispositions. Each cutter or contact point of the drill means is preferably made of hard material eg. tungsten carbide or tungsten carbide reinforced with diamond or PDC wafer; the wafer may be up to 3 mm e.g. 0.5-2.5 mm thick, while a stud carrying the wafer supported by the hard material may be of 10-50 mm such as 15-25 mm diameter. The said cutter or contact point may be directly or indirectly (using a stud), rigidly or flexibly mounted on the said surface of the second member. When a stud is used, it may be of tungsten carbide as commonly used. The outer wafer edge is the cutter edge and may extend along all of one side of the stud. When one of the cutter orientations needs to be maintained, a keying device which secures only that orientation can be present or the stud can be preshaped such that this orientation will be secured eg. with an elliptical cross section.

The first member is rotated by the drillpipe and in turn rotates the second member, the torque being transmitted from the first to second member. The same component of the assembly may provide both the holding and the torque transmission means, or separate components may be used for each of these means. Thus this component of the assembly may lock the first to the second member, against relative movement in any direction and therefore provide the holding means, and also provide the torque transfer means while allowing tilting of the cutters with respect to second member; in this form, the first and second members may if desired be integral. Alternatively this component of the assembly may lock the first and second member against relative movement in the axial direction but allow relative movement in an angular (i.e. twisting) direction in which case a separate torque transmission means is required. The holding means keeps the first and second members together and usually transmits the weight from the drill string to the second member, to provide the weight on

bit (WOB). The transmission means may comprise at least one elongate member e.g. a pin or bolt extending through said second member to engage at least one groove or slot in said first member; if desired the locations of the pin and groove/slot in the first and second members may be reversed. The transmission means may also comprise a co-operating pair of a radial extension or extensions e.g. star or gear shaped, and a corresponding groove(s) or recess (es), one on each of the first and second members. In the case of this co-operating pair, the first and second members are preferably held together with the aid of a threaded locking ring, which engages threads on the second member, e.g. internally facing threads, and bears against or towards at least one corresponding projection or outwardly extending ridge on said first member. Other corresponding pairs of interacting components on the first and second members may be used e.g. other cranked or polygonally shaped components and recesses to provide the torque transmission means.

The means allowing tilting may be in relation to the first and second members, with the drill means fixed relative to the latter, and in this case the drill means may be cutters or roller cones; preferably the means allowing tilting is between said first and second members. The means allowing tilting may be in relation to the second member and the cutter, with the first member fixed relative to the former and in this case the drill means are preferably cutters and not roller cones; preferably the means allowing tilting is between said second member and cutters. The means allowing tilting may also be between all 3 i.e. between first and second members and the cutter. The angle of tilt may be up to 15°, such as 1-15° preferably 4-10°.

The extent of possible tilting between the first and second member, or second member and cutter, may be until they come into contact with each other thereby restricting further tilting, but preferably further tilting before contact is restricted by a tilt restriction means. The latter may allow some free tilting when the assembly is at rest (when no load is applied), as well as when

it is in use, but preferably the tilt restriction means is a medium which provides some stiffness (resistance) against tilting movement, the stiffness being less than that of the first or second member.

The first and second member, or the second member and cutter, may be capable of small lateral or transverse movement relative to one another eg. lateral movement of first and second members of less than one hundredth the bit diameter. Thus the rotating axis of the second member may be capable of lateral movement relative to that of the first member, as well as or instead of the capacity for tilting movement when the first and second members are tiltable. Some axial movement of the first and second members may also occur, but only in association with lateral or tilting movement. The present specification describes further the tiltability features and the assemblies suitable for providing it, but the same general principles apply as well to the lateral movement feature; preferably the means allowing tilting is present in the assembly of the invention with means allowing lateral movement optionally present.

In a first type of embodiment of the invention, the second member is tiltable with respect to said first member to allow relative pivotal movement, but not axial movement. The first and second members are spaced apart but held together by the holding means, and are free to tilt relative to one another, though preferably the degree of tilt is restricted by tilt restricting means, which is preferably present in the space between the members. The tilt restricting means may be at least one elastomeric spacer, eg. of uniform or non uniform thickness such as at least 0.2 mm or 0.3 mm or 1mm thick, such as 0.2-5mm or 1 - 3mm thick restricting tilt and 0-0.5 mm eg. 0.1-0.3 mm thick restricting torque. Increasing bit diameters allows thicker tilt restriction means eg. up to 10 mm.

The spacer is usually such that the first member can tilt relative to the second member against the resistance of the elastomeric spacer. This approach in general applies whatever the

nature of the torque transfer means, e.g. as described above. The spacer may extend axially (i.e. parallel to the longitudinal axis of the bit) when the torque transfer means comprises also the means for holding the first and second members together, but may extend radially (i.e. normal to the longitudinal axis of the bit) when the torque transfer means does not so hold said members, e.g. when a locking ring is also needed, as described above; preferably the spacer extends both axially and radially. When the tilt restricting means allows tilt under no applied load, there is still a gap between the spacer and at least one of the members. However said means preferably allows substantially no tilt at rest so the spacer contacts both members, but allows freedom to tilt when the assembly is in use, e.g. because of the compressibility of the spacer, so the two members are pivotally movable in use under applied load.

The first and second members may each have an elongate conduit through it, the two conduits co-operating to allow flow of drilling fluid; if it is desired not to allow any leakage of said fluid through said gap between the members, then preferably a flexible pipe, e.g. a reinforced pipe of plastic materials extends through said conduits to provide the desired fluid passage. Otherwise the gap may comprise sealing means, which may also be the elastomeric spacer.

In the second type of embodiment of the invention, at least one cutter, and especially all said cutters are tiltable with respect to said second member. The cutter may be adhered to the second member with an elastomer which also provides the spacer. The cutter may be mounted on a stud which is in a hole or socket in said second member, and adhered thereto with a layer of adhesive to restrain the stud from removal from the hole or socket and provide the facility for tilting; other restraining means may be used. Such restraining means include co-operating combinations of grooves and ridges or projections or other bearing surfaces in the stud and hole/socket, with optional assistance of at least one ball and or spring, or an elastomeric stud catcher or the hole or

socket may be of outwardly decreasing cross section (especially in combination with the stud catcher). In relation to use of the other restraining means, there may also be at least one elastomeric spacer e.g. an O-ring, which may be friction fitted on the stud or in the hole or socket or at least partly received in grooves in the stud or hole or socket. If desired the hole or socket may not have been formed e.g. by drilling in the second member, but may be formed e.g. by moulding a matrix material to form a sleeve for insertion into a preformed hole in the second member; the spacer may then be placed in the hole/socket with the stud and the entire body (ie. the sleeve with spacer and stud) then inserted into the second member.

The spacer may be elastomeric. It may be formed in situ from a liquid settable material which cures to an elastomer, such as an epoxy or polyurethane resin. The components of the assembly on either side of the intended spacer may be joined together mechanically or placed in the desired place relative to one another and then the liquid poured into place, with the optional aid as desired of a plug for a central passage in the first and second member and/or a ledge or trough outside the two members to aid transfer of the liquid into the space between the 2 members. In the case of the cutter, the liquid may be poured into the hole or socket and then the cutter or stud carrying the cutter inserted into the uncured material. The liquid may be inserted at atmospheric pressure, or higher or lower pressure, in order to obtain a prestressed stage for the joint, to increase its strength for the high loading. The liquid polymerizes at room temperature, or higher if desired or necessary, to form an elastomer, usually one of compression modulus, which is up to 1000 times e.g. 100-1000 times lower than that of the material of the bit body, and may be $0.1\text{-}10 \times 10^9 Nm^{-2}$.

More than one elastomer may be used in different places in the spacer if desired, especially ones with different properties e.g. different moduli or adhesive/sealing characteristics; in this case the liquids would be poured and set in situ sequentially.

The elastomer may also be preshaped, especially for use in the space between the first and second members, or for example as stud catcher. The preshaped bodies may be as rings or squares or gaskets, or other bodies of complex geometry. Preferably for use with the studs, they are in the form of O-rings. The preshaped elastomeric material may be unfilled or filled with a solid additive e.g. alumina, and may be of the same compression modulus range as described above. Examples are epoxy resin, natural rubber, tetrafluorethylene polymers eg. "TEFLON" polymers, "ERTALON", polyurethane and rubber elastomers such as styrene butadiene and neoprene rubbers as well hydrogenated nitrile or standard nitrile rubbers. Use of the preformed shaped elastomeric spacers reduces the construction time by avoiding the time for polymerization and also allows for maintenance, repair or reuse of the spacer.

Preferably the elastomer has a Shore A hardness of at least 80 to reduce extrusion under load and a compression modulus which is 0.1 or less e.g. 0.01 or less such as 0.001-0.1 of that of steel.

The elastomer may be used as such as the spacer, or may be in the form of a layered body with at least one elastomer layer, e.g. 1-4 layers, and at least one metal layer e.g. 2-5 layers; the layers may be bonded together if desired. In the case of gaskets or other preshaped bodies, the elastomer may be restrained from extrusion by a metal frame.

Instead of an elastomeric spacer allowing restriction of tilt in the Assembly, there may be used other materials for achieving that purpose, such as preshaped springs such as helical springs under compression, belleville springs or hollow springs or springs combined with a damper. Another form of the tilt restriction mechanism can involve a hollow elastic body e.g. A hollow cylinder such as a toroidal metallic body, or can involve a body eg. an elastic body adapted to contain a compressible fluid, e.g. a gas such as air or an inert gas. The deflated body may be inserted at least partly in the space between the first and second

members (or second member and cutter) and then may be filled with the fluid e.g. inflated. If desired the body may extend into grooves or recesses in one or both of the first and second bodies. The body may be in the form of a band e.g. of reinforced rubber like a tyre or in the form of a tube eg. a torus. The inflation may be to a set pressure, or the pressure may be modifiable e.g. to increase if the load increases either automatically or following instruction by an operator; pressure control means capable of achieving this are well known in the literature on downhole pressure control engineering. If the torque is low, and the pressure in the inflated body high then that body may act itself as the torque transmission means as well as the tilt restricting means.

The assemblies of the invention may be dynamically more stable than known bits without the tilting means, can rotate more smoothly and uniformly and have an increased lifetime due to reduction in the frequency of damage or dislocation of the cutters, especially when moving between formations of different or variable hardness.

The present invention is illustrated in the accompanying drawings in which Fig. 1 represents a Cross-section of a known bit assembly shown schematically,
Fig. 2 represents an axial Cross-section through a schematic bit assembly of the invention while
Fig. 3 provides more detail on such a bit assembly, Figs. 4, 5, 6A, 7A, 8, 9, 10 represent axial cross-sections through other bit assemblies of the invention, while Fig. 6B, 7B and 7C represents transverse sections AA in Fig 6A and 7A respectively.
Figs 11 - 17 represent sketches showing schematically dispositions of cutters on studs in holes in the second members for use in the assemblies of the invention.

Referring to schematic Fig.1, a known drill bit assembly has a shank 1 with a thread 8 for engaging a drilling string (not shown) and having set of cutters 3 rigidly mounted therein. The shank is integral part of the bit body so, when in use, the

cutters are rigidly connected to the drill string.

Figure 2 shows schematically an inter relation between shank 21, bit 22 and cutters 23, in which bit 22 has a mouth 24 containing a flexible matrix as spacer 25 into which extends shank 21. There is also shown to a distorted extent the position of shank 21 when the bit 22 is tilted with respect to the shank, hence remaining in contact with the formation 25.

Fig. 3 provides more detail on the bit assembly of Fig. 2. and has shank 31, bit 32, cutters 33, mouth 34 and spacer 35, analoguous to items 21-25 in Fig. 2. But Fig.3 also shows bolts or pins 36 rigidly fixed to and extending through bit 32. The bolts 36 enter longitudinal axial groove recesses 37 of shank 31 in order to enable transmission of torque from the shank 31 to bit 32, but there is sufficient clearance between bolts 36 and recesses 37, so that coupled with the presence of elastomeric spacer 35 the bit 32 is able to tilt or rotate up to 10° relative to shank 31. Fig. 3B shows a section AA of Fig. 3A illustrating the relative location of bolts 36 entering recesses 37 in shank 31. The clearance shown in Figs. 3A and 3B between bolts 36 and recesses 37 allows a small lateral movement of bit 32 relative to shank 31. A bit assembly according to Fig.3 of 40mm diameter has been shown in laboratory tests to drill much more smoothly and more concentrically than a corresponding rigid assembly according to Fig.1. In the test the weight on bit (WOB) was slowly increased while the bit was rotated at constant speed. When the WOB was above a certain level, the bit vibrated so much that it did not remain in contact with the surface being drilled. In the test, this limiting WOB for the assembly of Fig.3 was about 3.7 times than that for the assembly of Fig.1. Moreover the drilling with the Fig. 3 assembly ran much more smoothly than that with the Fig. 1 assembly.

Referring now to Figure 4, the assembly comprises a hollow shank 41 separated from a hollow bit 42 by a flexible cup shaped spacer 45 which has 2 radial parts 45A, 45B joined by an axial part 45C Mounted on the bit 42 distant from the shank 41 is a set

of cutters 43, shown schematically. Shank 41 has screw thread 48 for engagement with drill pipe (not shown). Distant from said thread 48, the shank 41 has an inward ledge 49 leading to a nose 410 in which are disposed 6 circumferential recesses 47 (only one of which is shown for convenience). Bit 42 has a hollow or mouth 44 generally adapted to receive nose 410 and a shoulder 411 to receive ledge 49 but in both cases separated therefrom by spacer 45. Bolts or pins 46 are rigidly fixed in and pass through bit 42, and interact with recesses 47 to secure shank 41 to bit 42 and allow torque to be transferred between them (in the manner shown in Fig 3B), but also via interaction with spacer 45 to allow tilt movement of bit 42 relative to shank 41, against the restriction of spacer 45. Pins or bolts 46 may be secured further in place by a welded belt (not shown).

Bit 42, like shank 41, has an axial passage 412 for drilling fluid, and bit 42 also has outlets 413 for that fluid. Cutters 43 are located on bit 42 in an arrangement known per se eg. on a double parabolic profile.

The clearance between all opposed surfaces of bit 42 and shank 41 may be the same, but is preferably larger between axial surfaces than radial ones (as shown).

Fig. 5 shows an assembly the same as in Fig. 4 but with a plug 514 to seal axial passage 512 from the spacer 55 between bit 52 and shank 51. Surrounding bit 52 just below spacer 55 is a ledge ring or trough 515, which is used temporarily during construction of the assembly for directing a liquid elastomer between bit 52 and shank 51 prior to its setting in situ to form an elastomeric spacer 55 and sealer.

Fig. 6 (as 6A) shows an assembly with an alternative to the separate bolts or pins 46 of Fig. 4 and Fig. 6B shows a section through the assembly of Fig 6A. In Fig. 6A, there are a shank 61, bit 62, cutters 63, thread 68, nose 610, mouth 64 and central passage 612, all equivalent to items 41, 42, 43, 48, 410, 44 and 412 of Fig. 4. Instead of separate pins 46 rigidly passing through bit 42 and entering recesses 47, the present embodiment

has inward facing teeth 616 integral with bit 62 (and machined therein) and inward facing recesses 617 in bit 62 which loosely mesh in the manner of gear cogs with corresponding recesses 67 and teeth 618 formed in shank 61. Between all the teeth and their recesses is an elastomeric spacer 65. A locking ring 619 surrounds shank 61 and has outward facing threads 620 which engage corresponding inward facing threads 621 on bit 62. Ring 619 bears upon spacer 65 to lock bit 62 onto shank 61 but allow tilting. In this embodiment bit 62 and shank 61 are in direct contact, on one side of teeth 618 in an axial direction, but not on the other side, though (not shown) spacer 65 may separate bit 62 and shank 61 from contact anywhere.

In Fig. 7A, there is also shank 71, bit 72, cutters 73, thread 78, nose 710 mouth 74 and central passage 712, ring 719 and threads 720 and 721 all equivalent to items 61, 62, 63, 68, 610, 64, 612, 619, 620, 621 of Fig. 6. In this case instead of teeth 618 on shank 61, there is on shank 71 and extending circumferentially an outward facing ridge 722, which may be of gradually increasing diameter (as shown) or radial and is separated from locking ring 719 by spacer 75; this spacer provides the facility for tilting bit 72 relative to shank 71. As shown in Fig. 7B and 7C, the torque transfer mechanism comprises a series of loosely enmeshing cogs 723 and 724 of chamfered (Fig. 7B) or square (Fig. 7C) cross section and formed in the mouth 74 and nose 710 of the bit 72 and shank 71 respectively. Space between the cogs 723 and 724 is at least partly filled with further elastomeric spacer 75.

Fig. 8 concerns a modification of the assembly of Fig. 7 in which a flexible reinforced elastomeric pipe 825 having an externally threaded lower member 826 and outwardly extending upper member 827 attached thereto is located in the central passage 812. The upper member 827 bears on a corresponding ridge in passage 812 and is sealingly held in place by a threaded ring 828 engaging threads 829 inside passage 812. The lower member 826 of the pipe 825 arrangement sealingly engages corresponding threads on the

mouth 84 of bit 82. Fluid moving through passage 812 is thus constrained to flow through the pipe 825 and not to leak past elastomeric spacers 85 in mouth 84. This assembly is useful when the drilling fluid is of high velocity and/or high pressure and prevents "wash out". Also (not shown) the flexible pipe 825 arrangement may be used in a modification of the assembly of Fig. 4 - 6, 9 or 10.

Fig. 9 shows an alternative method of providing the tilt facility and can be adapted also to transfer torque. Bit 92 has two inward facing circumferential recesses 930 in the upper section of its mouth 94; recesses 930 are connected to the outside of bit 92 by way of conduit 931, fitted with valve 931A. Intermeshing teeth and recesses 916 and 97 are located and perform as do members 616 and 67 in Fig. 6. Located in each of recesses 930 is a continuous flexible band 932 closed in an inward direction but open in an outward direction thereby forming a toroid with an outward opening (931); this band may if desired be reinforced e.g. with steel circumferential reinforcement (not shown). The inward face of band 932 bears on shank 91 when in use. To construct this assembly, bands 932 are located in their recesses 930, glued in place and then shank 91 is inserted into mouth 94. Then compressed gas e.g. air or inert gas is passed into band 932 through conduit 931 and valve 931A is closed. The pressurised band 932 enables bit 92 to be tiltable relative to shank 91. If desired (not shown) band 932 may be replaced by an inflatable tube to form a toroid. In both alternatives the pressure and the coefficient of friction between the band 932 and shank 91 may be adapted such that the band 932 may be used to transmit torque, and then it would be possible to reduce the number of teeth and recesses 916 and 97, or omit them completely.

Fig.10 shows a schematic modification of the assembly of Fig. 6, in which locking ring 1019 bears upon an upper outer surface 1034 of a multi-layered gasket 1035 having external and internal metal rings or washer 1036 separated by elastomer layers 1037. An upper inner surface 1038 of the gasket 1035 bears upon

an inwardly extending surface 1039 of shank 101. The gasket 1035 is locked in place on the nose 1010 of shank 101 by shank locking ring 1040 which bears upon the lower inner surface 1041 of gasket 1035. Lower outer surface 1042 of gasket 1035 bears upon an outwardly extending ledge 1044 in mouth 104 of bit 102. Sealing rings eg. O-rings 1043 are provided above and below upper and lower outer surfaces 1039 and 1042. Torque transfer means (not shown) may be as in Figs. 4-9 but having the interaction between each opposing face and the corresponding shank 101 and bit 102 rather than eg. shank 41 and bit 42. Instead of horizontal rings 1036 to reinforce the elastomer layers 1037 there may be used vertical metal tubes (not shown) separated by elastomer layers 1037 but having in this case no tube extending completely between opposing faces of the gasket so there are elastomeric layers between the tube and the external surfaces 1034, 1038, 1041 and 1042.

Figure 11 shows, in schematic close up, a relation between bit 112, cutter 114 and flexible matrix 113. Bit 112 has a recess 1150 generally adapted to receive cutter 114 (also known as a stud), but be separated therefrom by elastomeric matrix 113. Cutter 114 has a PDC wafer 1151 mounted on a chamfered edge 1152 with cutter 114 having a flat end 1153 (a wear flat) and chamfered side 1154. In use wafer 1151 is forced against the rock formation 1155, causing cutter 114 to tilt in a clockwise direction thereby lifting the wear flat 1153 off formation 1155, increasing the relief angle, hence increasing the ability to penetrate the formation, an advantage in addition to the decrease of vibration level. The gap between cutter 114 and bit 112 is preferably such that it allows a maximum tilt of up to 10 degrees. This gap depends in the depth of insertion of the cutter 114, the cutter width and cutting force level exerted on the cutter. For example, the gap between cutter 114 and bit 112 is at least 1mm and usually 2-4mm, when the depth of insertion in the recess 1150 is 10-30 mm and width of cutter 114 is 10-25 mm.

Fig. 12 shows an improvement in the arrangement of Fig. 11

with the recess 1250 containing a large circumferential slot 1256 and a plurality of smaller circumferential grooves 1257 in the curved recess wall 1268 and also in the flat end 1269 of the recess 1250. In the slot 1256 are two balls or cylinders 1259 separated by springs 1260. In grooves 1257 are elastomeric O-rings 1261. Cutter 124 is held in the recess 1250 by the spring/balls 1259/1260 but is able to tilt against the elastomeric rings 1261. The balls 1259 provide a pivot point. Lab tests have shown that such an arrangement will accept loads of up to 4000 Kg.

Fig. 13 shows a modification of the arrangement of Fig. 12 in which the cutter 134 is received in a preshaped socket 1362, which has the slots/grooves 1356 and 1357 etc. as 1256 and 1257 in Fig. 12 but the socket 1362 itself is received in a recess 1363 in the bit 132. Socket 1362 may be of harder material than the bit 132, eg. when the socket is of sintered carbide and bit is of steel or matrix material.

Fig. 14 shows a modification of Fig. 12, in which the recess 1450 is of outwardly reducing cross-section e.g. of generally frustoconical shape. A hollow frustoconical elastomeric stud catcher 1463 is in the recess 1450 and surrounds and grips the cutter 144, which is separated from the end face 1464 of the recess 1450 by a spring 143 or a resilient component eg. an elastomeric spacer (143) which forces the cutter 144 against the grip of the catcher 1463. If desired a layer of adhesive (not shown) may be present between catcher 1463 and cutter 144 to increase the retention of cutter in the socket. Catcher 1463 may be retained in recess 1450 by means of an internally facing lip 1465 to recess 1450.

Fig. 15 shows the separate socket approach of Fig. 13 applied to the reduced cross-section recess approach of Fig. 14 and is self explanatory.

Fig. 16 shows a modification of the arrangement of Fig. 12, with cutter 164 retained in bit 162 and spaced therefrom by elastomeric O-rings 1661. Fig. 16A shows the arrangement with a cutter 164 having an outer flat end 1653 and PDC wafer 1651. The

flat end 1653 may have been machined or moulded, in a new cutter or may have been worn flat as in a used cutter. Fig. 16B shows the arrangement of Fig. 16A under load in use and shows the wafer 1651 contacting the formation, and the tilt allowing the relief angle to increase. This device is very suitable for entering harder formations.

In Fig. 11-16, the cutter is substantially perpendicular to the bit, but can be inclined either towards or away from the direction of movement of the bit as shown in Figs. 17A - E which illustrate 4 variations on the Fig. 16 arrangement. Extra support may be needed in a Fig. 17A approach to stop the cutter 174 being pulled out in use. An example of this support is shown in Fig. 17D, in which cutter 174 has a ledge 1766 separated from a corresponding lip 1765 on recess 1750 by elastomeric spacer 173. In Fig. 17E recess 1750 for cutter 174 may be in a protrusion 1767 of the bit 172, as in a bladed bit. The arrangement in Fig. 17C can be valuable when drilling from a hard to a soft formation e.g. from sandstone to shale. Lowering the WOB will increase the relief rake and hence allow a cutter which has been flattened by the hard sandstone to be very active in the softer shale.

The bit assemblies of the invention are less prone to vibration and can give improved benefits as described above; these benefits can be shown in use. For many purposes however it is desirable to be able to test bits in the laboratory and hitherto such testing was done there with apparatus comprising a rigid bit, short drill string or collar and motor. But we have found that drilling characteristics observed with such laboratory apparatus did not often parallel those found down hole, so that the bits broke more often down hole than was predicted from the tests. We have invented a laboratory drilling apparatus which can more closely create types of observed down hole phenomena.

The present invention provides a laboratory apparatus for simulating drilling which comprises (a) at least one rigid rotatable body connected directly or indirectly to each of (b) a drill bit for contacting a simulated bottom hole surface, and (c)

means for rotating said body and bit, wherein at least one of (a) and (b), and (a) and (c), and (a) and another (a) when present, is separated by a flexible connector.

This apparatus can be capable of creating a large range of dynamic phenomena found in the field. Each rigid rotatable body used need only weigh up to 10-20 kg for ease of handling.

In the apparatus the rigid rotatable body simulates part or all of the drill string. The body is usually a cylinder, and made of steel, or other materials e.g. other metals such as aluminium or thermoset synthetic material or tungsten carbide, if it is desired to alter the inertia of the body. The bodies have connecting means e.g. threads at each end and usually an inner passage through them for fluid or gas.

The apparatus also comprises at least one flexible connector joining the rotating means to the rigid rotatable body and/or that body to the bit and/or one rigid rotatable body to another rigid rotatable body. Preferably there is a separate flexible connector between the rotating means and the body, and each body to the next body and the last body to the bit. To the last body, a bit can be rigidly or flexibly connected, depending upon which situation is investigated. When a reference situation has been created, either with a rigid or flexible bit, bit designs and particularly the properties of the scaled flexible connector can be studied. The properties of the bit so obtained in the laboratory, can be related to the actual bit.

Each flexible connector can be adhered to the body, rotating means or bit, but preferably is connected to it by a screw thread. Each connector therefore preferably has an outwardly extending thread on each face of a pair of opposing radial faces adapted to engage threads on the body, rotating means or bit; conveniently a pair of plates each having thread extending axially therefrom is spaced apart by an elastomeric material in the form of a layered body. The layered body may if desired be adhered together or alternatively may be kept together with a pin or bolt between the plates which still enables the layered body to flex in a

transverse direction. It is also possible to have one or more internal plates separating elastomeric bodies in a multi-layer structure, the elastomeric bodies being, if desired, of different compression modulus. The elastomeric material may be as described above.

The other essential ingredients in the apparatus are the rotating means e.g. an electric motor, especially of variable speed, and also the bit, whose design is being tested.

In use the bit bears upon a test piece of material to be drilled. In order to vary the angle of contact of bit on the piece and to simulate bore hole confinement, the rigid rotatable bodies preferably pass through a simulated borehole wall. This wall may comprise rings, especially a series of rings defining a path in which the rigid bodies rotate, to create a simulated well bore profile. These rings may vary in inner diameter, outer diameter, height, mass, rigidity, inner surface friction coefficient, and may be made of different materials e.g. steel, concrete, synthetic polymer, whether thermoplastic thermoset or elastomeric, or rock. Alternatively to the rings there may be used a number of facially touching tiles made e.g. from rock, concrete, synthetic polymer, compositions comprising concrete, polymer, metal, sand or sand with polymer; a hole can be drilled through the tiles to provide the simulated borehole.

The test piece upon which the bit acts, is the simulated bottom hole material which may comprise natural rock, concrete, or compositions comprising these or sand or metal powder. Simulated rock of variable physical characteristics may be made from mixtures of clay and granular material e.g. sand, silicate or carbonate in different proportions and with different degrees of compaction.

The whole test apparatus may be 1 - 15 m high, conveniently 1 - 4 m high, with the rigid cylinders of 50 - 500 mm long and 2 - 200 mm wide such as ones 300 mm long with diameters of e.g. 5, 10 or 100 mm. Flexible connectors may be 10 - 60 mm long and of 5 - 100 eg 10 - 90 mm diameter. The apparatus preferably has at least

one of its natural frequencies (axial and torsional) not greater than 10 or 5 Hz, eg. 0.05 - 10 Hz, such as not greater than 1 Hz. The apparatus may be wall mounted or mounted in a frame, which may be portable. The rigid bodies (a) drill bit (b) and rotation means (c) with the flexible connector(s) of the invention can have an equivalent ratio of stiffness to mass of at most 1000 sec^{-2} e.g. 100-0.01 sec^{-2} especially 60-0.1 sec^{-2}.

If desired the apparatus may also include means for passing fluid e.g. water or gel around the bottom hole assembly or down the central drilling passage of the cylinders and flexible connectors.

The laboratory apparatus of the invention may be able to create at the bit conditions more realistic to those experienced by bits down hole than we have found possible with previous laboratory drilling apparatus with very rigid shafts and no flexible connectors. Thus it has often been found, that, with bits tested in such apparatus, the bits break more easily down hole (i.e. had a shorter life) than predicted from the laboratory apparatus results. Thus the apparatus of the present invetion can be used to provide an improved method of testing a drill bit. Furthermore the rings or plates of other materials defining simulated bore hole walls can be moved relative to one another to create different degrees of bore hole interaction to study the effect of the changes on the dynamic behaviour of the bit.

This aspect of the invention is illustrated in Figs. 19 and 20, in which Fig. 19 represents a schematic drawing of a complete testing apparatus and Fig. 20 represents a schematic section through a bit for use in that apparatus during construction.

Referring to Fig. 19, the apparatus has a motor 191, eg. AC non-synchronous electric motor or a controlled DC electric motor, which drives a series of rigid cylinders 192 and 193 which are themselves joined together by flexible connectors 194. Attached to the lowest cylinder 193 is a further flexible connector 194, in turn attached to a bit 195, each of the connector 194 and bit 195 can independently be rigid or flexible. The rigid cylinders 192,

connectors 194 and bit 195 have a continuous bore through them (not shown) to allow passage of a drilling fluid. The rigid cylinders 192 and 193 are constrained to rotate through bores 198 in plates 199, which may be single ones e.g. a metal ring or a series of plates (1910) which may be tiles or other sheets simply lain on top of one another or laminated together. Bores 198 simulate the bore hole passing through rocks and provide confinement to the string. Bores 198 may be at an angle to vertical to simulate non-vertical drilling and the angle may be different in the location of different rotatable bodies to simulate a curved bore hole profile. At the top of the assembly of rigid cylinders 192 and 193 and connectors 194, two cylinders 192 and a connector 194 are located inside a pipe 1911 even more closely to simulate the casing and frictional effects therein. The bit 195 is in contact with a test piece 1912 being drilled. Test piece 1912 and the plates 199 are mounted in a frame 1913; the motor 191 may also be mounted on the frame 1913, or other beam support or separately supported e.g. on a wall, in both cases being mounted either rigidly or with freedom of axial movement. The whole assembly may be 1.5, 3, 5 or 10m high. The cylinders may be 1-10 kg, may be of ferrous metal e.g. steel and can be conveniently of 300 mm length and 5,10 or 100mm width. The flexible connectors 194 usually have two metal plates separated by an elastomeric body and each plate usually has connection means eg. an outwardly directed thread for joining to cylinders 192 and 193 or bit 195; the connector has a bore through it for the fluid. If desired the elastomeric body may be replaced by a spring.

If desired the cylinders 192 and/or 193 may contain sensors or other measurement equipment. The combination of inertia of the cylinders and flexibility of the connectors can be adjusted to provide a simulated drill string of vibration frequency of eg. 0.2 Hz, usually similar to that of a drill string which may have variable length but is usually several kilometers long.

Fig. 20 shows a cylinder 201 of inner diameter corresponding to the bit diameter for the apparatus. Inside cylinder 201 are a

series of blades 202, made eg. made of metal or from hard synthetic plastic e.g. thermoset resin, and especially with an elongate section 203 and a sharply curved section 204 (like a field hockey stick). The blades 202 are lightly glued in place to provide a bit with a known profile. The cylinder 201 is partly filled with moulding clay 205 or other inert malleable material so the blades 202 project partly above the clay. A shank 206 carrying a connecting thread 207 is located on the cylinder's longitudinal axis. Between the clay 205 and shank 206 is set resin 208. The whole assembly apart from the cylinder and the moulding clay constitutes a small scale bit, which bit can be assembled in the above order with settable resin added last; once the resin has set the bit can be removed from the cylinder 201 and cleaned to remove the clay, thereby revealing the blades 202 embedded in cured resin 208 in a bit. If desired the shank 206 or cured resin 208 may be drilled to provide fluid channels for cleaning the bit.

Claims:

1. A drill bit assembly, which comprises a first member and a second member, said first member being for attachment directly or indirectly to a drill string, and said second member carrying at least one means for drilling, which assembly also comprises means for holding said members together and for transferring torque and weight from said first to said second member, and means allowing tilting of or relative lateral movement of at least one of (a) said first member relative to said second member, and (b) said second member relative to said drill means.

2. An assembly according to claim 1, wherein said second member is tiltable with respect to said first member.

3. An assembly according to claim 2 wherein said first member engages said second member.

4. An assembly according to claims 2 or 3, wherein said second member is tiltable with respect to said first member against compressible means between said first and second members.

5. An assembly according to any one of claims 2-4 wherein said first and second members have a co-operating passage therein.

6. An assembly according to claim 5 which comprises compressible sealing means between said first and second members to prevent escape of fluid from said passage between said members.

7. An assembly according to any one of claims 2-6 wherein said holding means and torque transfer means together comprise at least one elongate member passing through said second member and engaging in at least one recess or slot in said first member.

8. An assembly according to any one of claims 2-6 wherein said torque transfer means comprises grooves or recesses in said first or second member engaging corresponding gear components in the other of said first and second members.

9. An assembly according to claim 8 wherein said holding means comprises a threaded locking ring surrounding said first member and engaging threads on said second member.

10. An assembly according to any of claims 5-9 which comprises a first member having a first elongate conduit therethrough co-operating with a second elongate conduit in said second member, said first and second conduit being in fluid contact by way of a flexible pipe.

11. An assembly according to claim 1 wherein said first and second members are integral.

12. An assembly according to any one of the preceding claims wherein said drill means comprises at least one cutter.

13. An assembly according to claim 12 wherein said cutter is tiltable with respect to said second member.

14. An assembly according to claims 12 or 13 wherein said cutter is adhered to said second member by an elastomeric spacer.

15. An assembly according to claims 12, 13 or 14 wherein said cutter is mounted on a stud, which is in a socket in said second member with means to restrain removal of said stud from said socket, and at least one spacer allowing tilting of said cutter with respect to said second member.

16. An assembly according to claim 15 wherein said spacer comprises at least one elastomeric O-ring in said socket.

17. An assembly according to claims 15 or 16 wherein said socket is in a separate body from said second member, said body itself being in a hole in said second member.

18. An assembly according to any of claims 15-17 wherein said restraining means comprises an elastomeric stud catcher in a socket which is of outwardly decreasing diameter.

19. An assembly according to claim 4 or 6 wherein said compressible means comprises an elastomeric spacer between at

least part of said first and second members.

20. An assembly according to claim 19 wherein said elastomer is at least one of a hydrogenated nitrile rubber, a nitrile rubber and a polyurethane, and has a Shore A hardness of at least 80.

21. An assembly according to claim 19 or 20 wherein said elastomer is derived from a settable liquid set in situ.

22. An assembly according to claim 19 or 20 wherein said spacer is a preformed ring or gasket.

23. An assembly according to claim 19 or 20 wherein said spacer is a layered body with at least one layer of elastomer and at least one layer of metal.

24. An assembly according to any one of claims 14, 15 or 19-23 wherein said spacer is at least 0.3 mm thick.

25. An assembly according to claim 4 or 6 wherein said compressible means comprises a hollow body adapted to contain a compressible fluid.

26. An assembly according to claim 25 wherein said compressible means also provides said torque transfer means.

27. An assembly according to any one of claims 1-13 wherein said second member is tiltable relative to said first member against a hollow cylinder or spring.

28. An assembly according to any one of the preceding claims wherein said means allows tilting of up to 15 degrees.

29. An apparatus for simulating drilling which comprises (a) at least one rigid rotatable body connected directly or indirectly to (b) a drill bit for contacting a simulated bottom hole surface, and (c) means for rotating said body and bit, wherein at least one of (a) and (b), and (a) and (c), is separated by a flexible connector.

30. An apparatus according to claim 29 which comprises at least 2 rigid bodies (a) spaced from one another and from (b) and (c) by flexible connectors.

31. An apparatus according to claim 29 or 30 wherein said body (a) is a rigid cylinder threaded to a correspondingly threaded flexible connector.

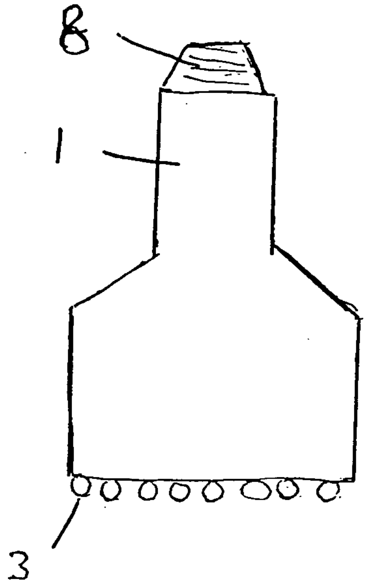
32. An apparatus according to claim 31 wherein said flexible connector comprises 2 plates each carrying a thread adapted to engage a rigid cylinder, said plates being separated by a flexible member.

33. An apparatus according to any one of claims 29-32 which also comprises a simulated bore hole comprising at least one bore member having a bore in which said rigid body can rotate.

34. An apparatus according to any one of claims 29-33 which has one of its natural frequencies not greater than 10 Hz, preferably not greater than 1 Hz.

35. An apparatus according to any one of claims 29-34 which comprises an axial passage through all of said rotatable bodies, flexible connectors and the drill bit.

Fig 1



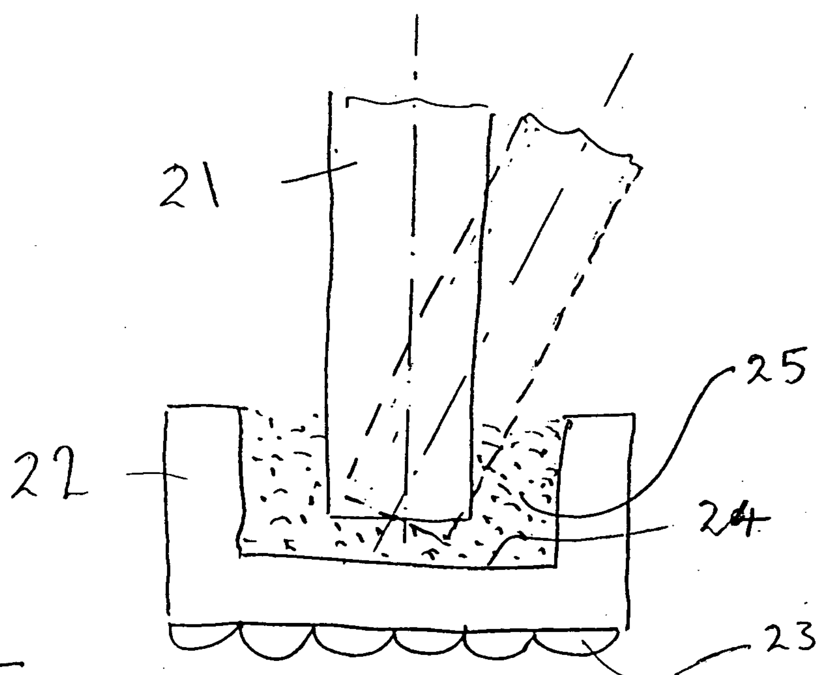


Fig 2

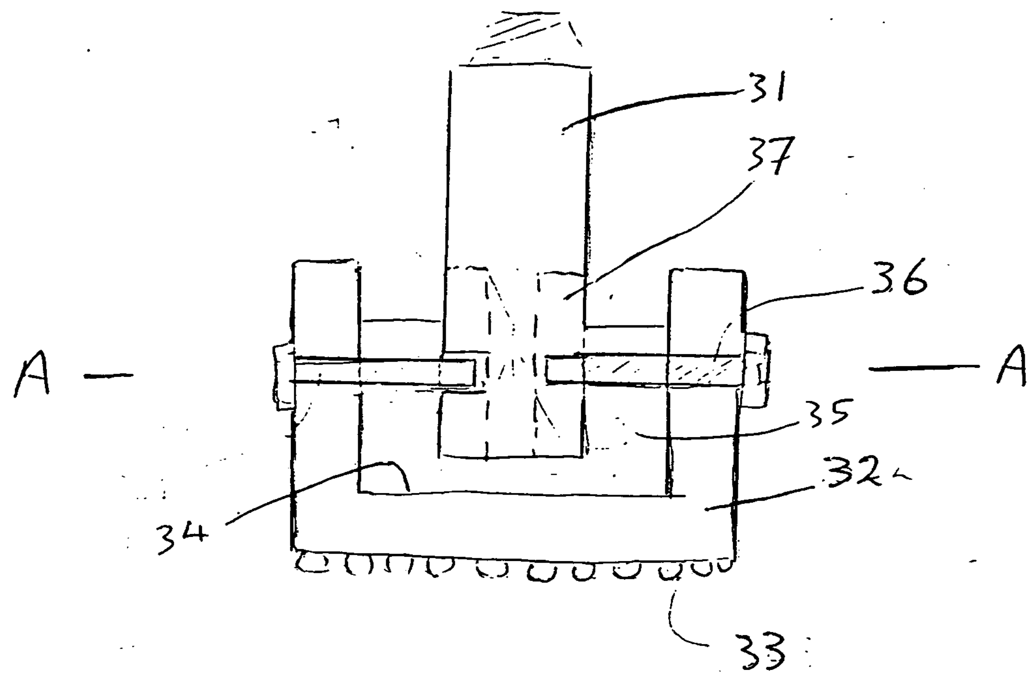


Figure 3A

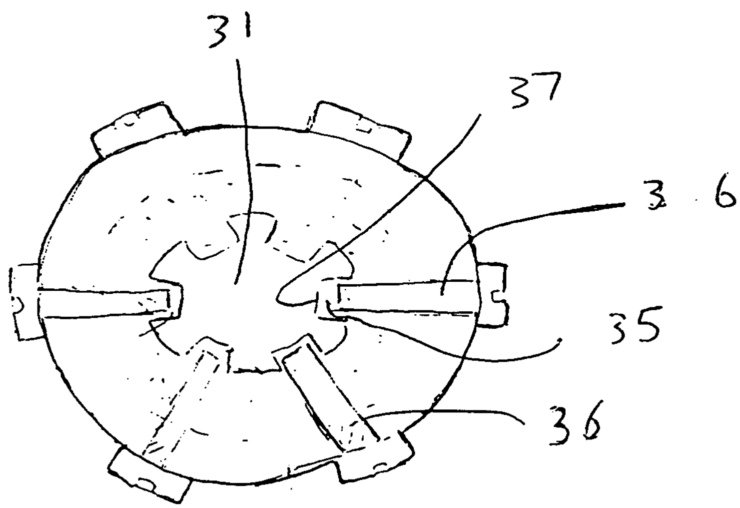


Fig 3B.

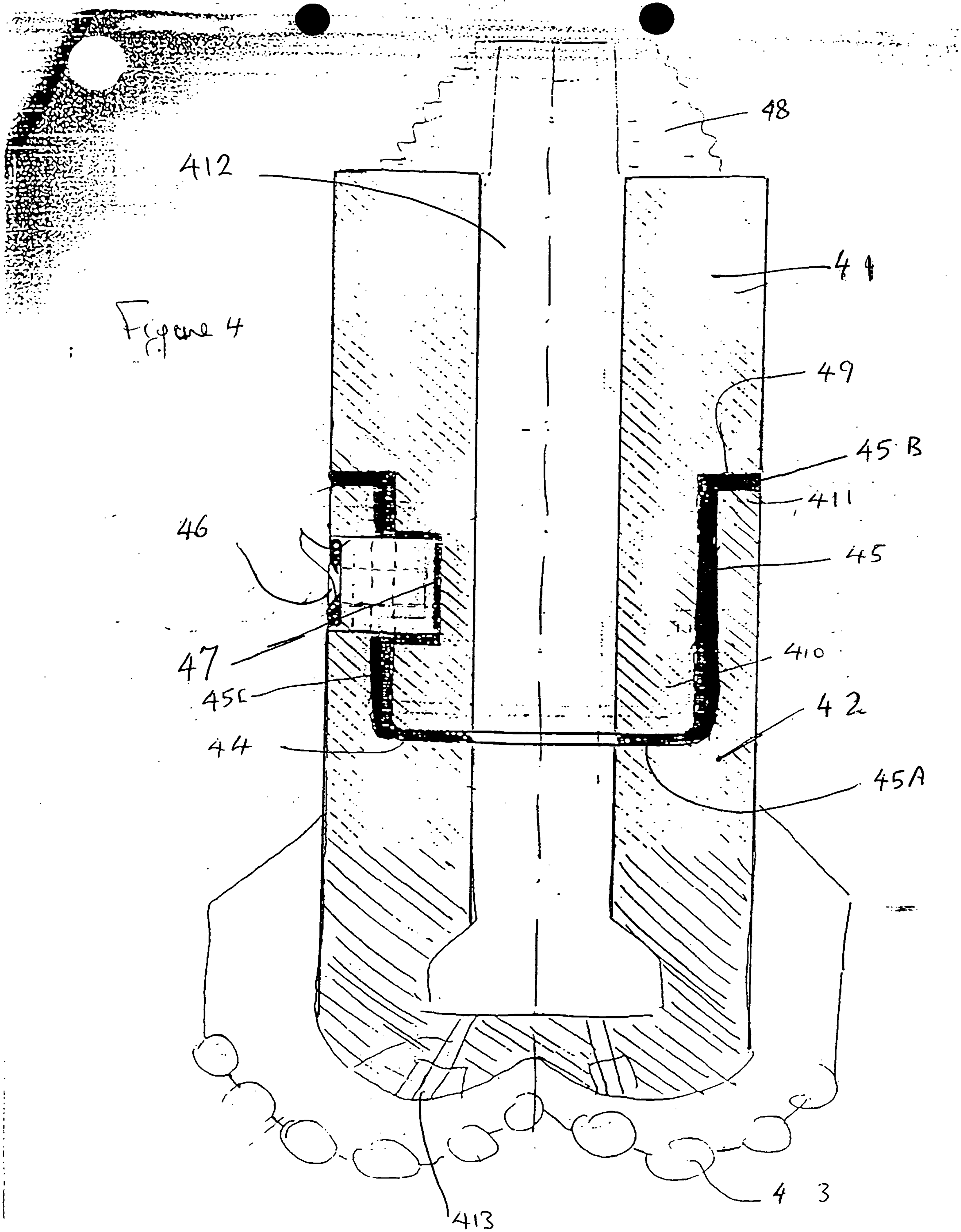


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Figure 4
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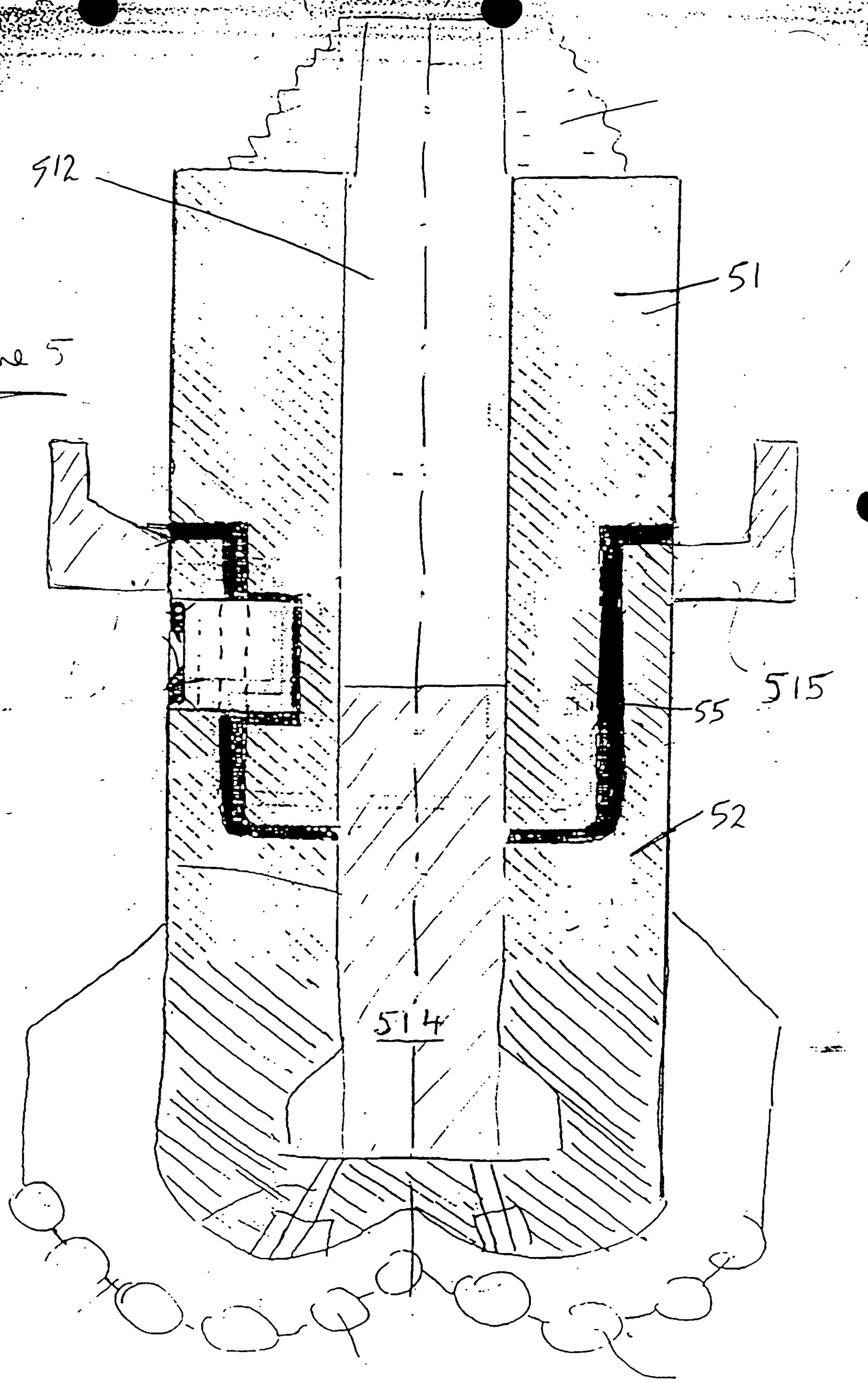
Figure 5



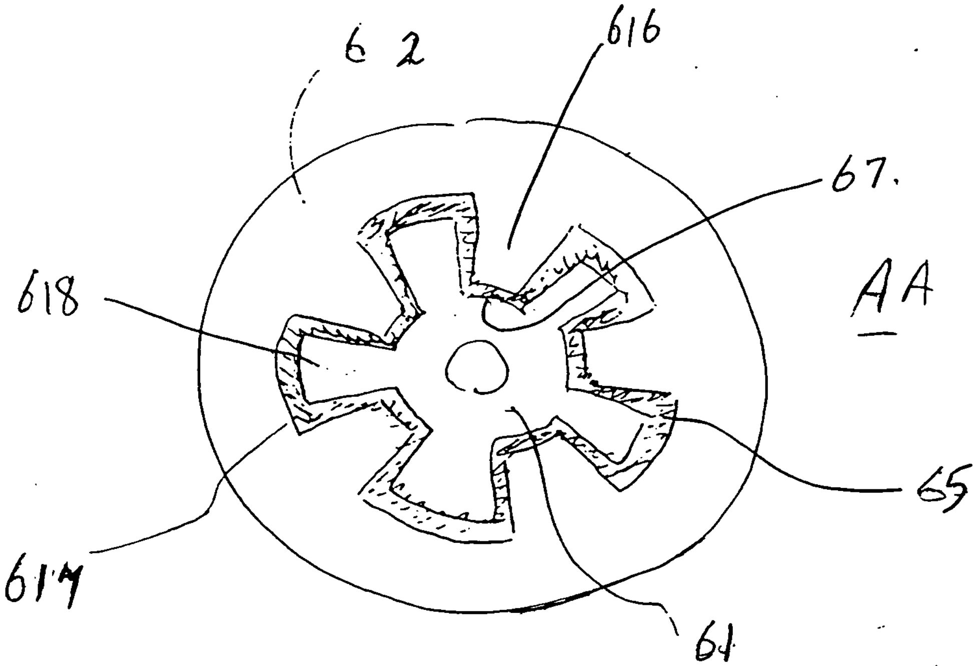


Fig 6B.

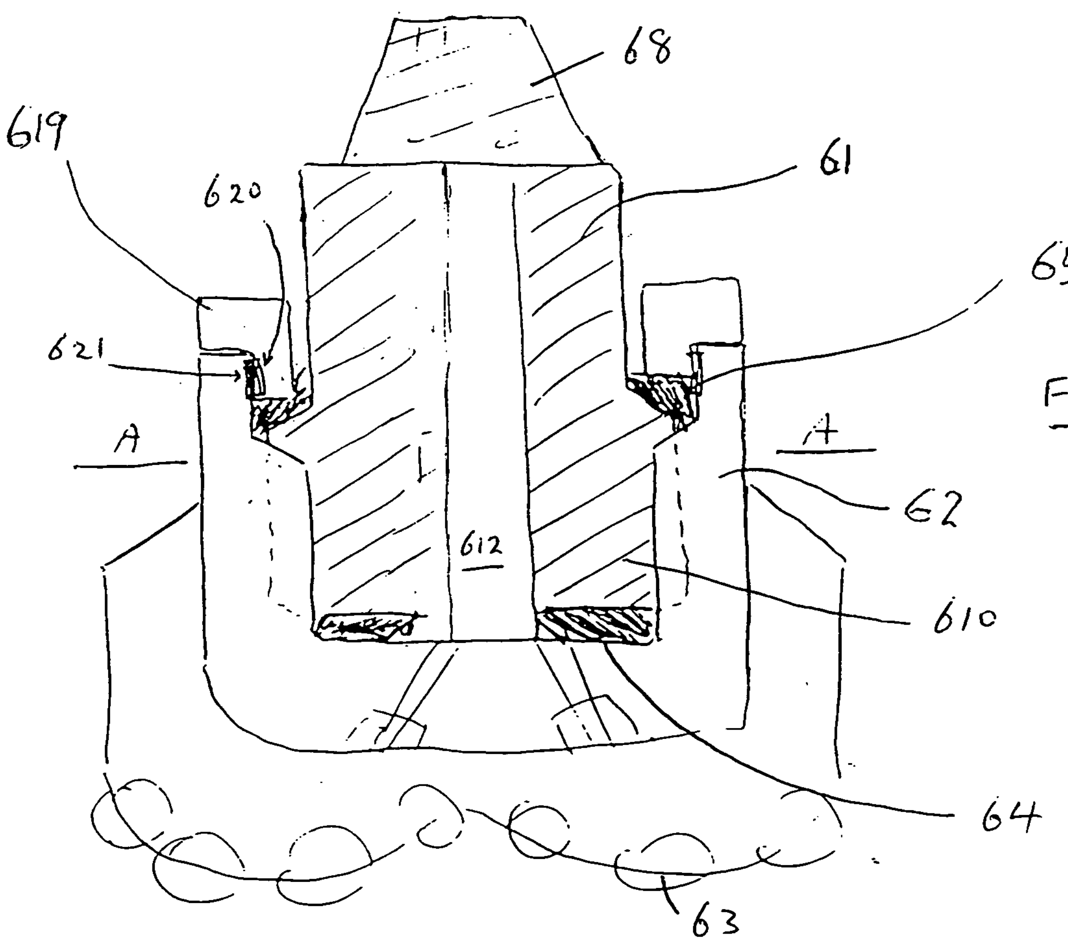
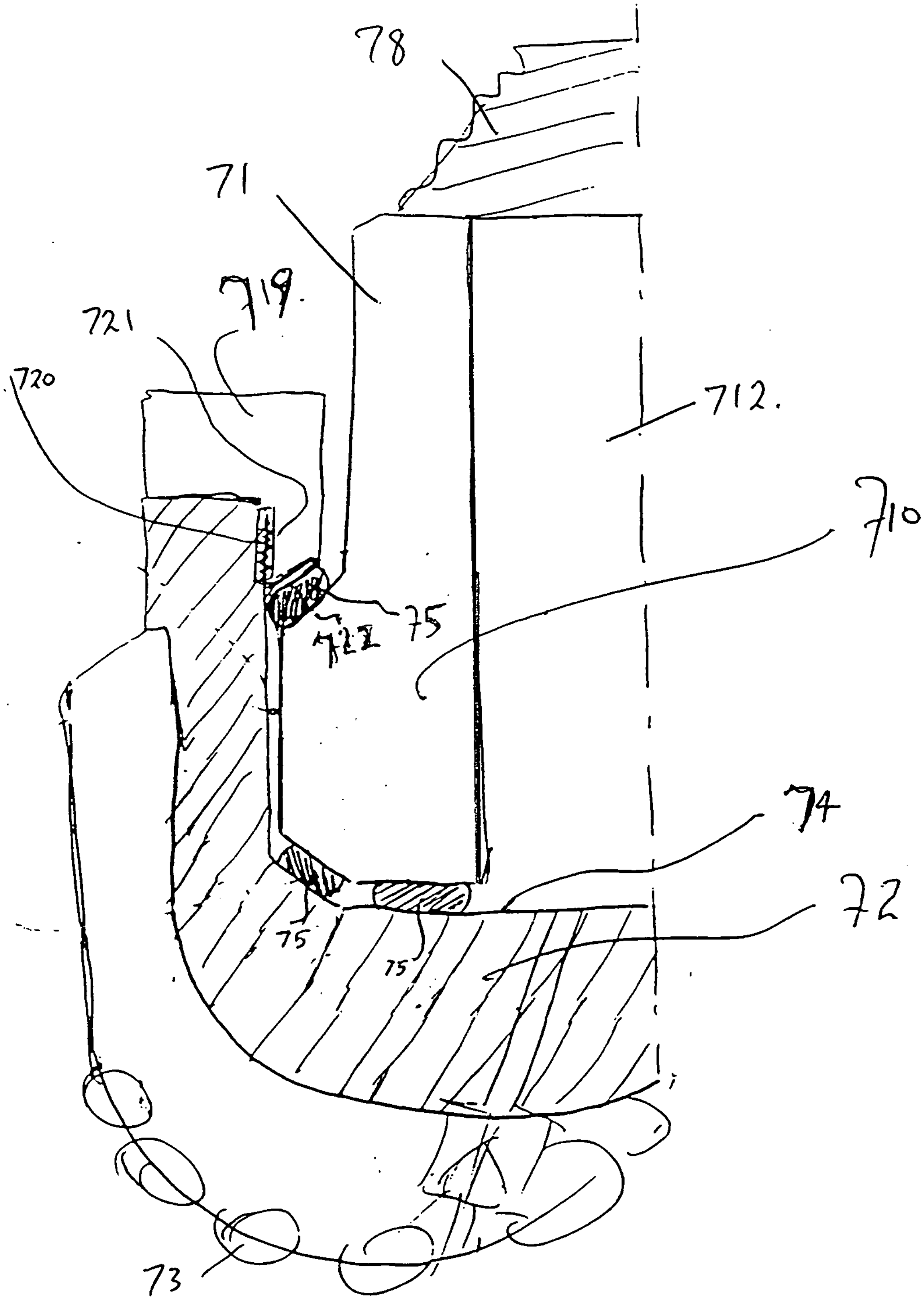


FIG 6A

Fig 7A.



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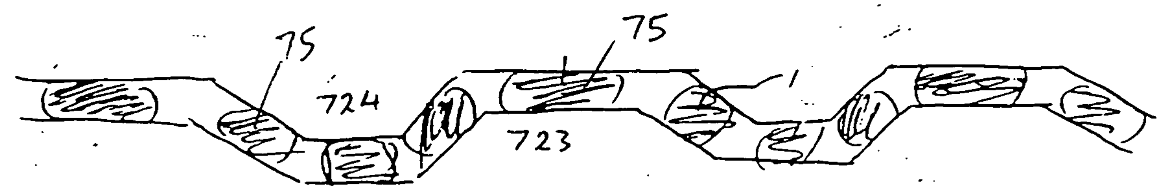


IG 7C

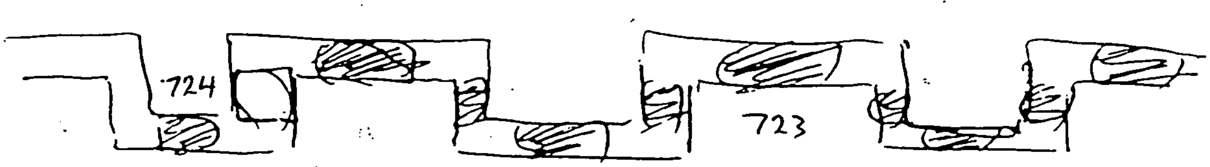
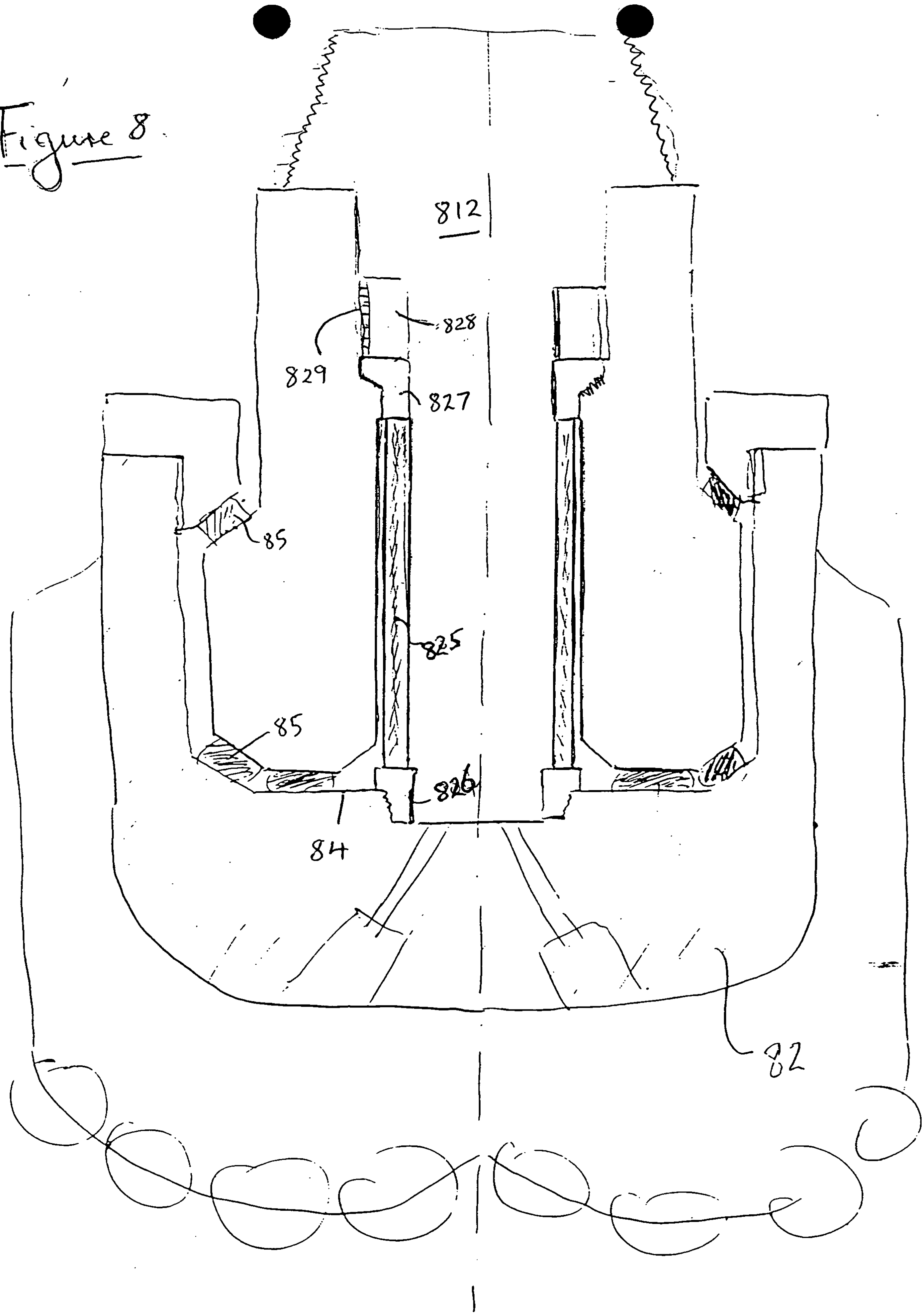


Figure 8



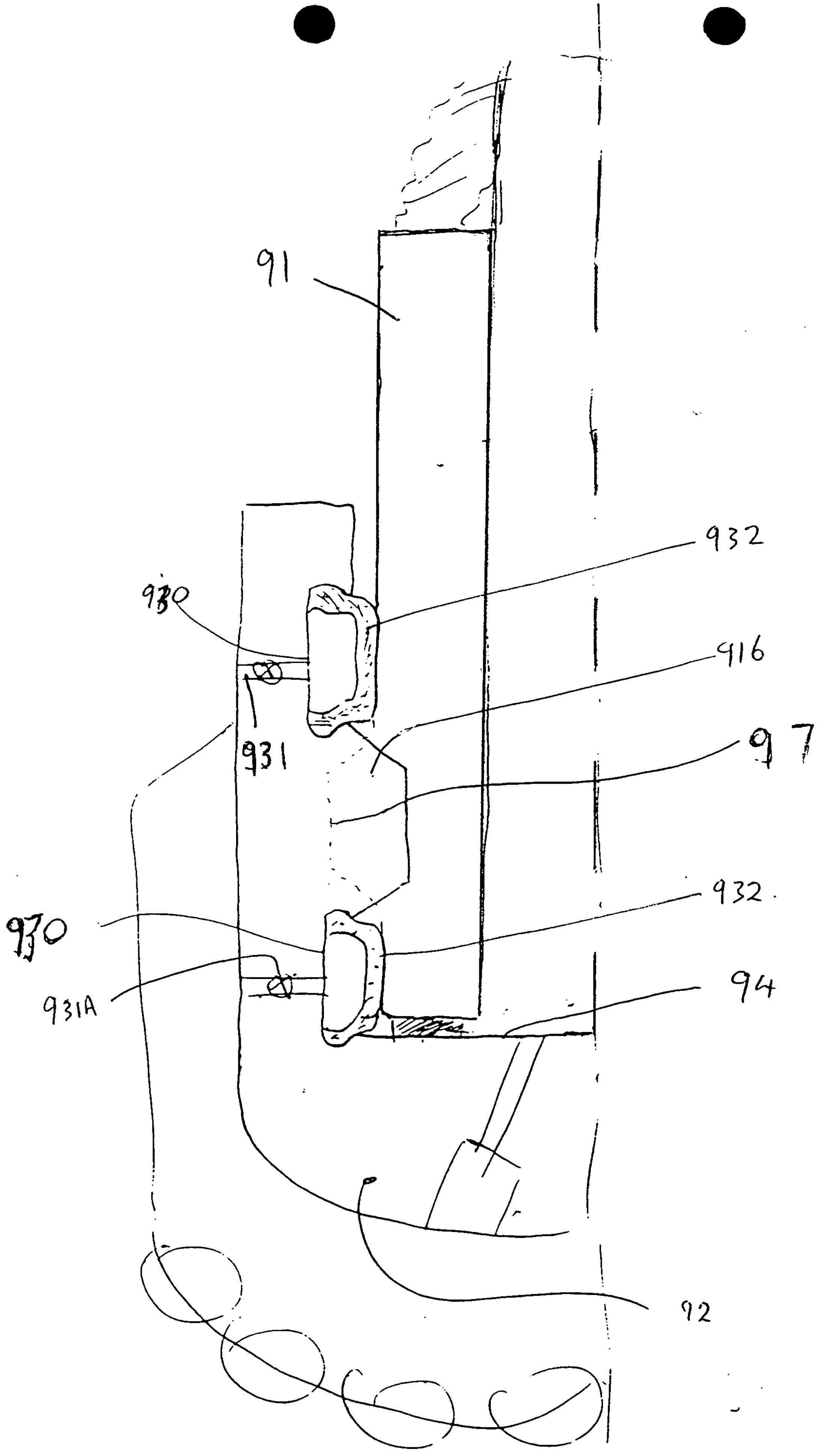
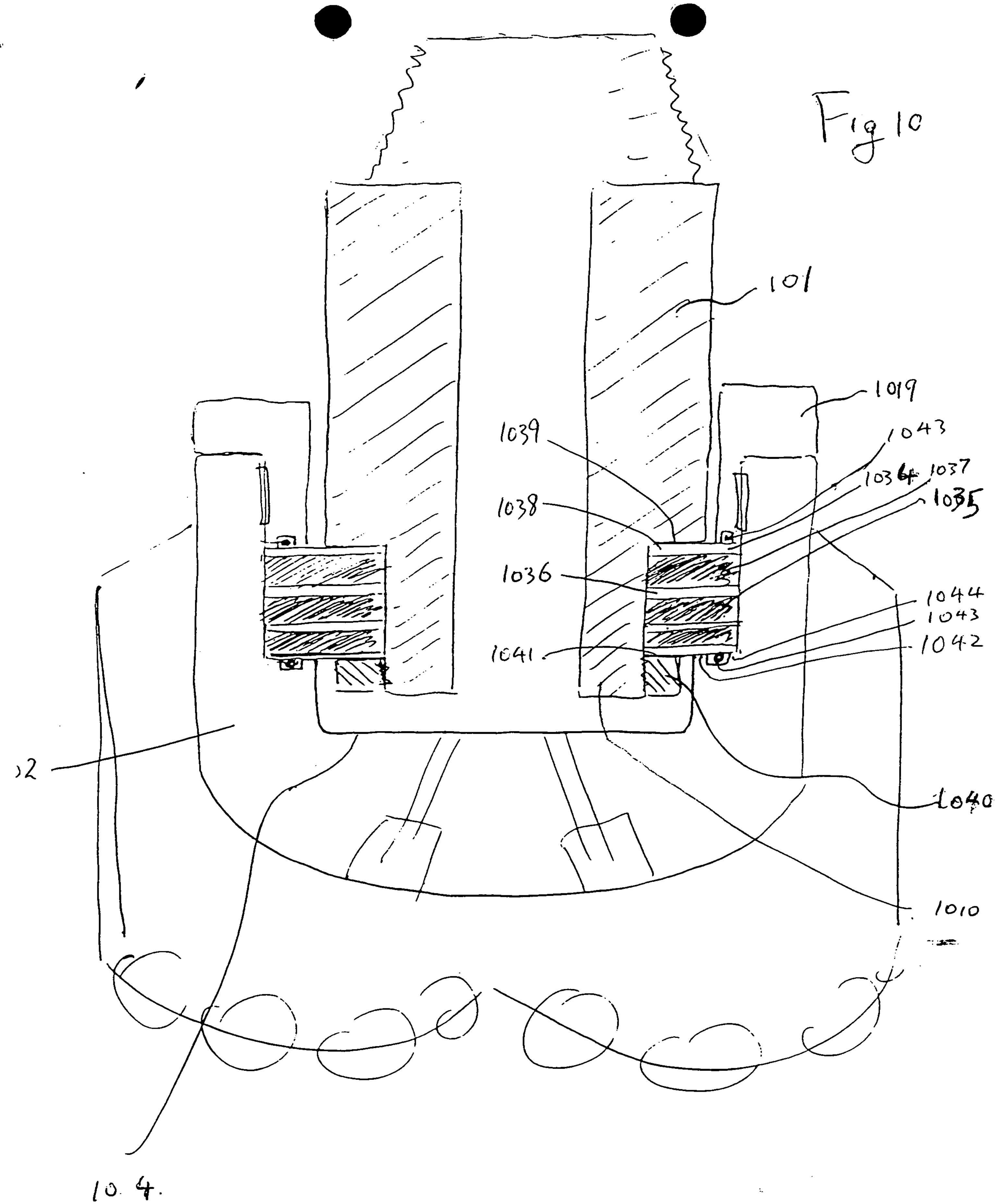


Fig. 9

Fig 10



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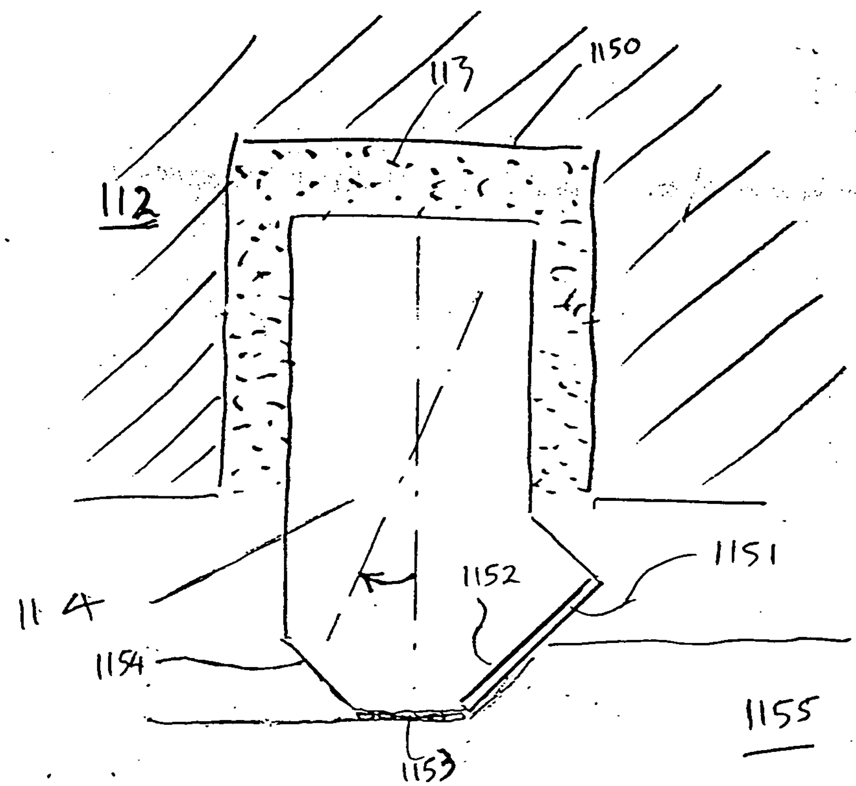
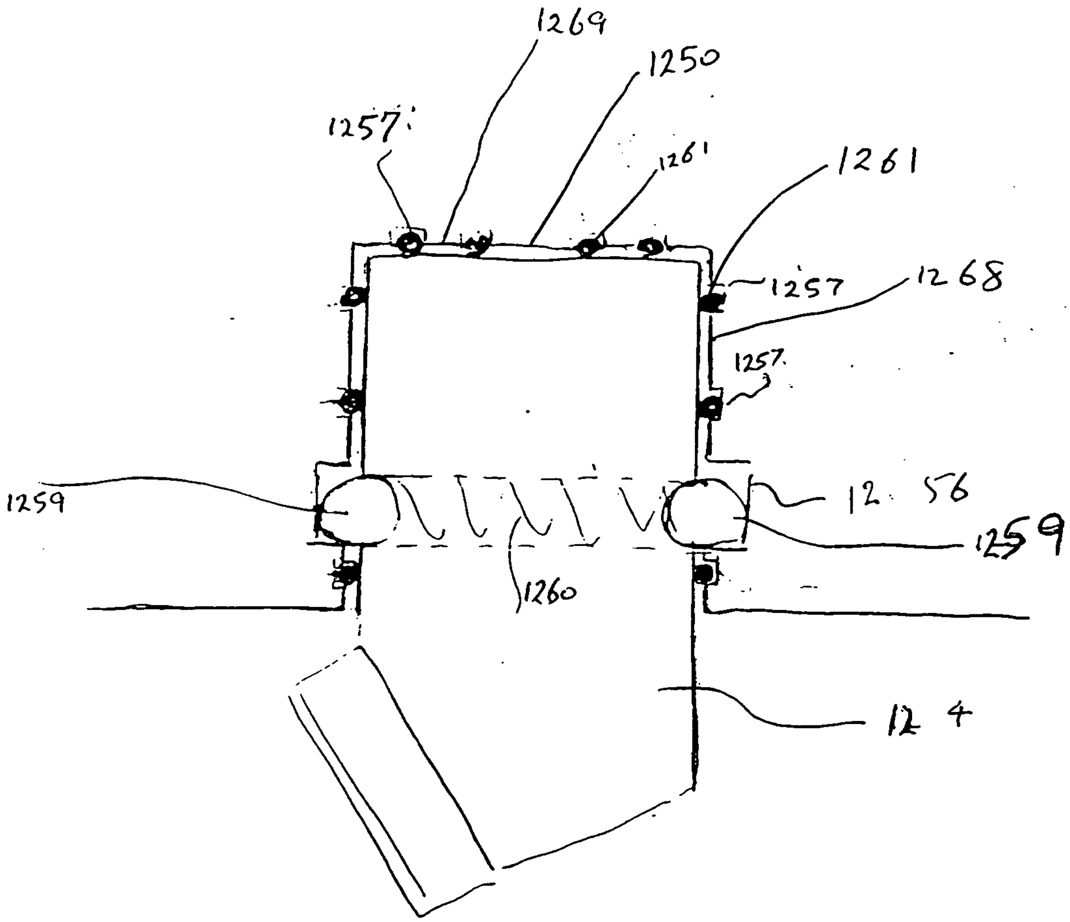


Fig 11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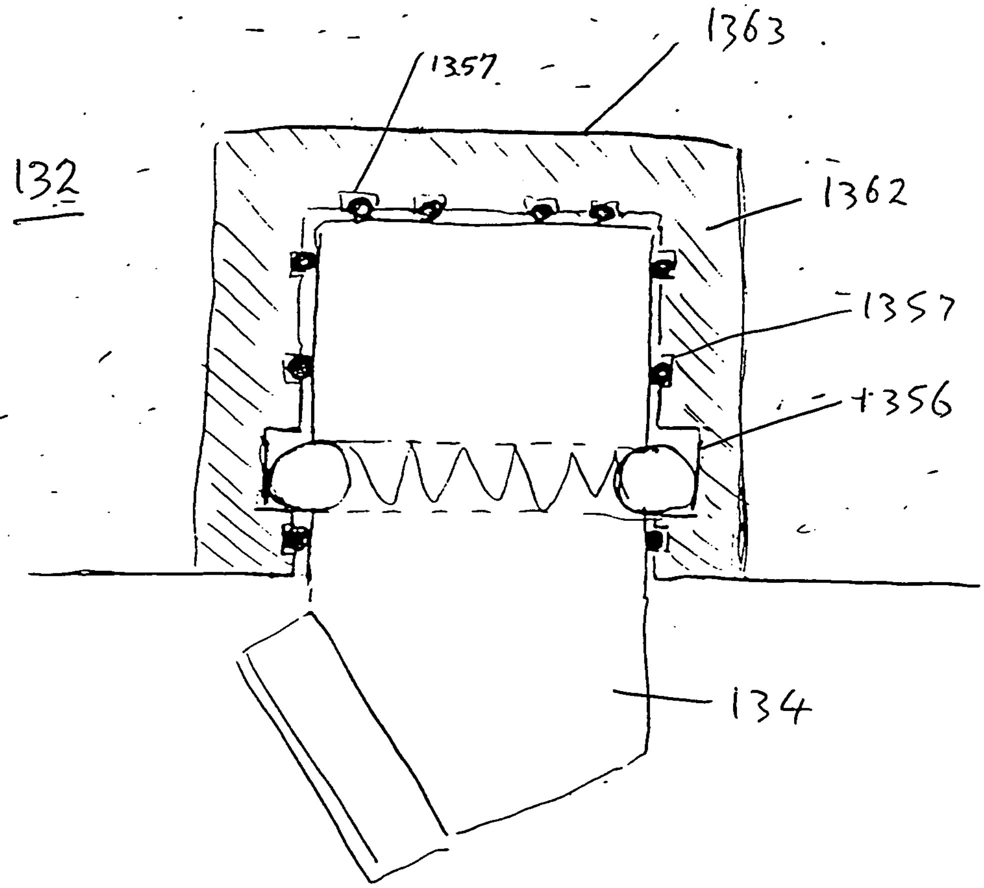
- Fig 12 -



- Fig 13 -

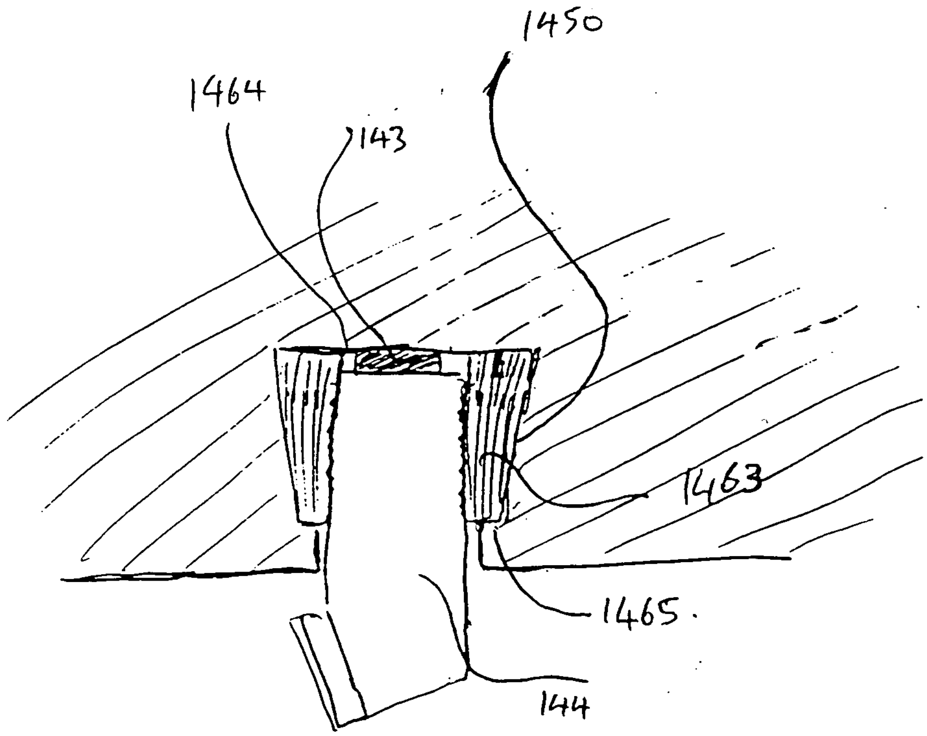


Fig 14

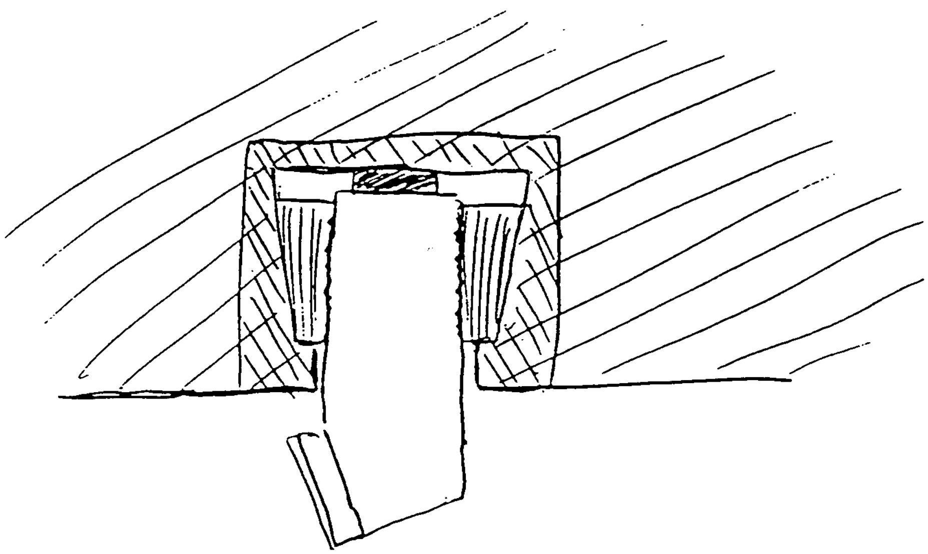
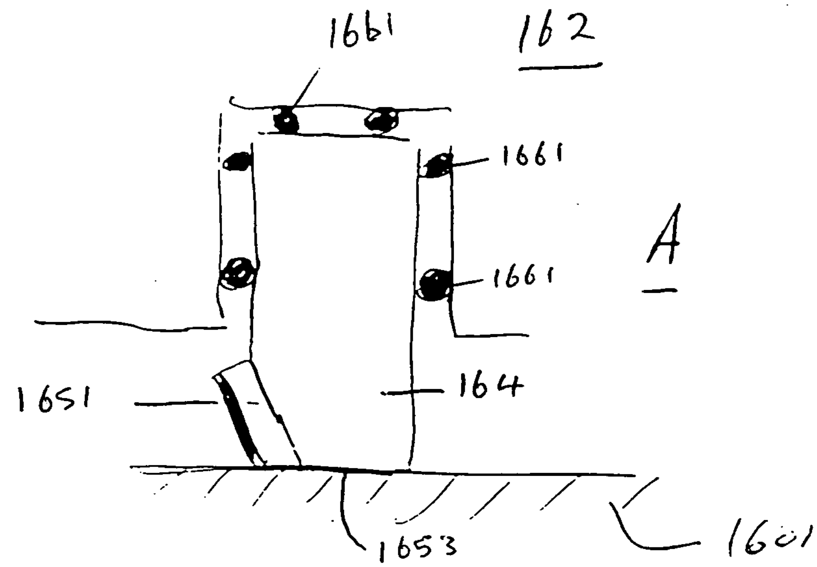


Fig 15.



A

Fig 16

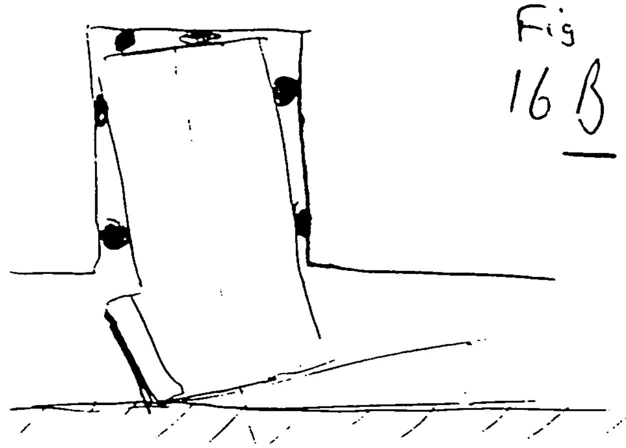


Fig 16 B

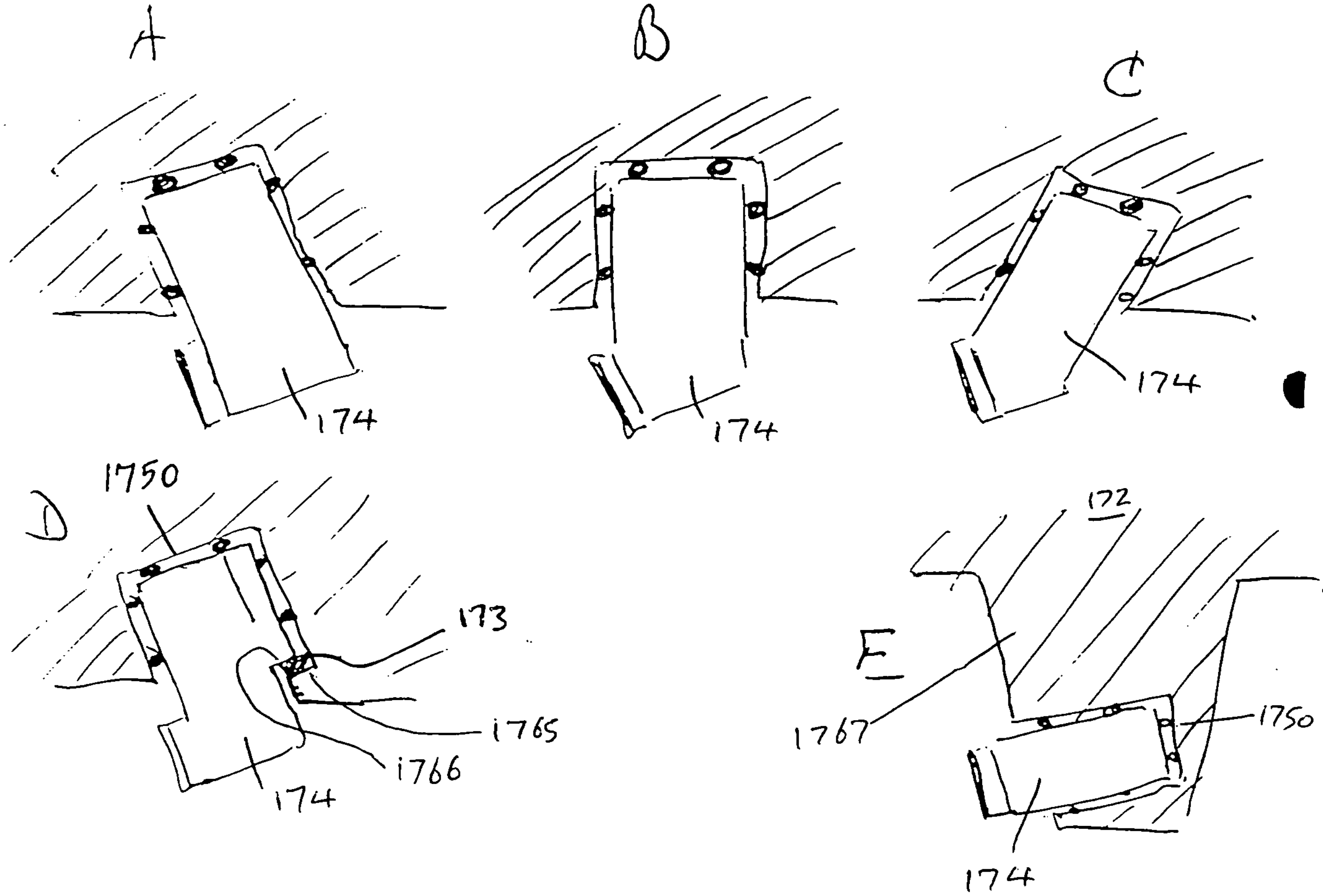


Fig 17

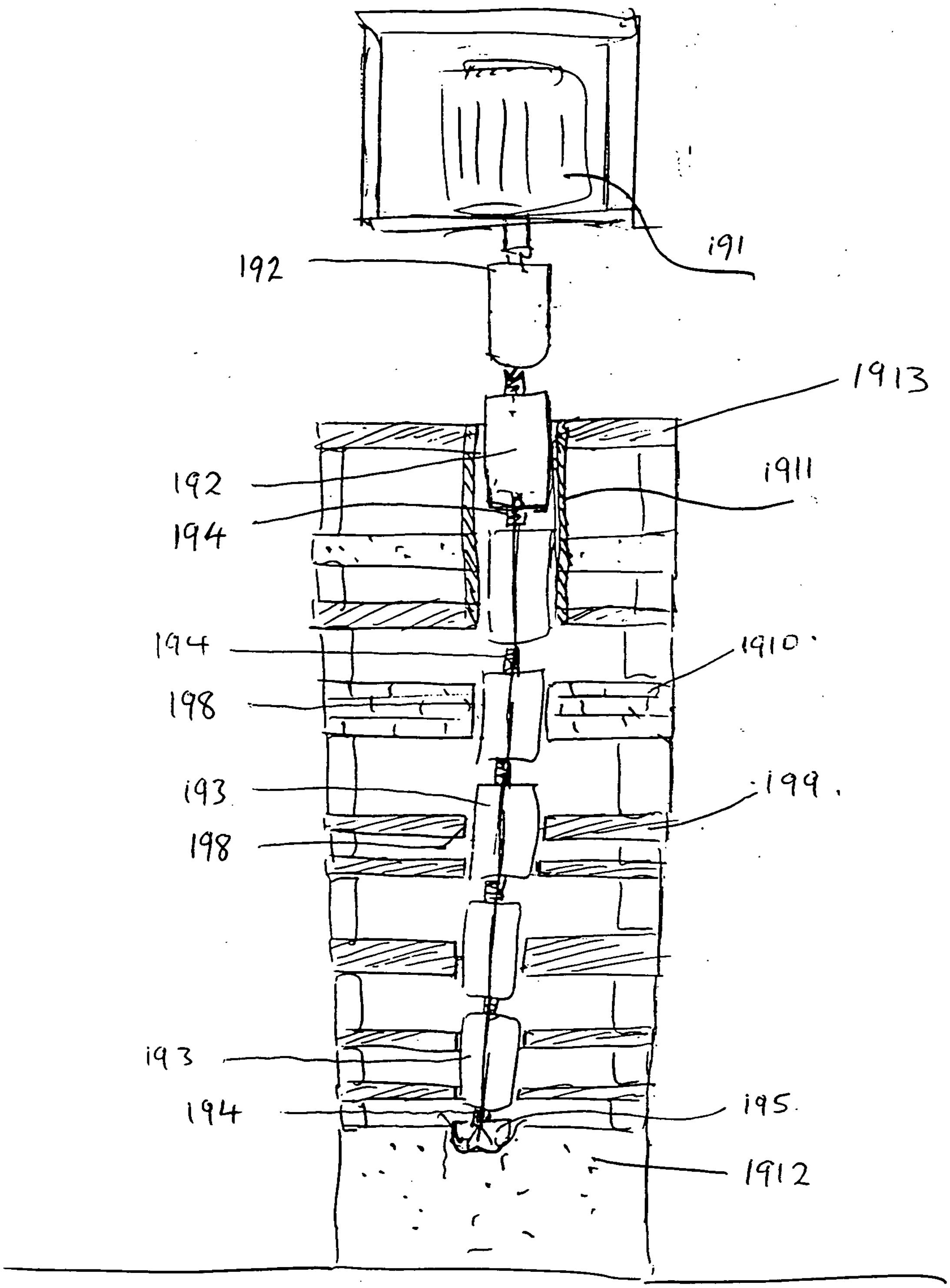

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Fig 19

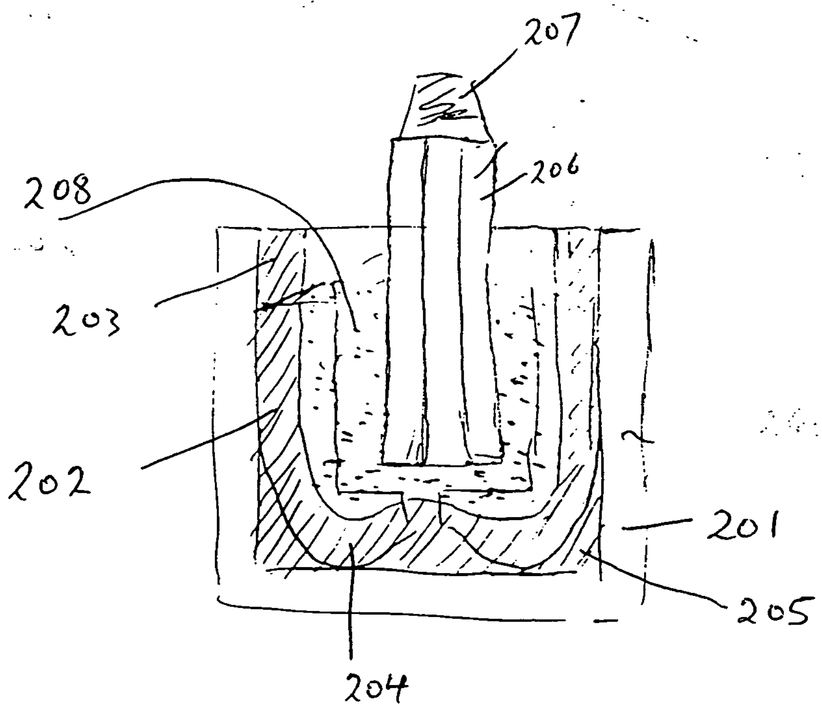

Figure 20